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Minimum Hand Haptic Perception Thresholds

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ABSTRACT

This paper is a short review of the recent state of the art relating to the study of vibration perception thresholds (VPT), sensed by the fingertip(s) of the human hand. To this end, papers regarding the topic of assessing VPT, released between 2011 and 2021, were collected and reviewed. Focus was given regarding the experimental set-ups, particularly the choice of algorithms and instruments used, the choice of body locations and frequencies to study, characteristics of the recruited subjects, and experimental duration. The main results each study reported were also analyzed. From this work, it became clear that although the choice of instruments and the characteristics of the studied populations tended to vary somewhat between studies, the reviewed studies had other aspects in common, such as the prevalent use of the von Békésy algorithm, the assessment of VPT on the finger pad of the index finger on all but one of the studies, and some overlap regarding the choice of analyzed frequencies.

Keywords: Vibration perception thresholds, Fingers, Sensory perception, Vibration, Tactile perception, Accessibility

INTRODUCTION

The perceptual basis and the neurophysiology of tactile perception are widely complex and are still under active research. The most well-known framework in vibrotactile perception is the four-channel theory, which states that four types of mechanoreceptors, sensory cells that detect deformation, are found in the glabrous skin of the human hand, which activate when mechanical stimuli are exerted on the skin. The four different sensing channels are different in how they respond to different mechanical stimuli and the type and pattern of energy to which they are sensitive to (Mills et al. 2016; Choi and Kuchenbecker 2013; Gandhi et al. 2011). Out of these four mechanoreceptors, two are especially attuned to detecting short-lived signals, such as vibrations. For a vibration stimulus to be perceive by humans, its amplitude needs to be above a certain threshold, called the Vibration Perception Threshold (VPT), which is dependent on several factors related to the vibration signal, the point of contact with the subject, and the subject's own individual characteristics (Basdogan et al. 2020; Culbertson et al. 2018; Jones and Lederman 2006; Chouvardas et al. 2008).

As the number of commercial actuators that are solely designed to provide haptic output is limited, many researchers have resorted to developing their own proprietary haptic devices, through the use of commonly available parts (Culbertson et al. 2018). One of the consequences of this is that, in the field of study of haptic feedback, many different instruments (vibrometers) and experimental protocols have been used throughout the literature to study how our brain notices and processes information regarding vibrotactile stimuli (Gandhi et al. 2011). The international standards for the assessment of mechanical vibration have provided a point of reference for scientists aiming to conduct research studies in the field of haptic perception, giving recommendations regarding the various components that a vibrometer should have, as well as recommendations regarding the experimental protocols to use to assess VPT. While the main focus during the elaboration of these international standards was regarding mechanical vibration and its use in clinical diagnosis, they can also be used in studies that are not exclusively conducted as part of medical research. Regarding the vibrometer's components, there standards recommend that it should, at the very least, be composed of a stimulator, through which a vibration stimulus is created, and a probe object, through which the stimulus is transmitted to the body location, with additional components, such as a firm surround around the probe, a finger or hand support structure, and a sensor to accurately discern the position of the probe, being optional. As for experimental protocols, these international standards recommend the use of at least one of two psychophysical algorithms, namely the staircase algorithm, which employs intermittent stimulation, and the von Békésy algorithm, which makes use of continuous stimulation. Intermittent stimuli is referred by these standards as being preferred, as it decreases the chances of a temporary threshold shift occurring due to a suprathreshold stimulus, as well as to introduce an interval where no extra stimulus occurs, which helps subjects differentiate between the sensations caused by the applied stimulation, and the background sensations that are present (International Organization for Standardization 2001; International Organization for Standardization 2003).

The goal behind the present study was to conduct a literature review of the state of the art of recent studies that assessed VPT on the fingertips, to build upon the work of Gandhi et al. (2011). As such, six papers, published between 2011 and 2021, which studied VPT at the fingertip/finger pulp of at least one of the subjects' fingers, were selected and analysed in this study. Focus was first given to the choice of psychophysical method and the characteristics of the vibrometer that was(were) used. Afterwards, focus was on which body location(s), frequency(ies), and population(s), was(were) studied, as well as how long the experimental procedure(s) lasted. Lastly, focus was given to the results obtained on each of the reviewed papers.

REVIEW

Algorithm

On all the papers that were reviewed in this study, the von Békésy algorithm was used on all of them to collect VPT data (Ekman et al. 2021; Ekman et al. 2019; Lundström et al. 2018; Dahlin et al. 2015; Mahbub et al. 2011; Tateno et al. 2011).

Vibrometer Characteristics

Some variability could be found regarding the choice of vibrometer used in each of the reviewed studies. Some authors used commercially available devices, such as the Vibrosense Meter 1 (Ekman et al. 2021; Ekman et al. 2019; Dahlin et al. 2015); the Brüel & Kjaer 1800/WH 1763 (Lundström et al. 2018); and the HVLab Tactile Vibrometer (Mahbub et al. 2011), while other authors choose to use equipment developed in-house (Tateno et al. 2011). Despite this variety of equipment, some common aspects between them could be found. One of these was that all instruments were limited to only delivering vibrations to, and collecting data from, one skin location at a time. As for how vibrations were delivered to the skin location, all instruments made use of a movable probe placed below the skin location, with a probe-head diameter of either 4mm, on all studies that used the VibroSense Meter I (Ekman et al. 2021; Ekman et al. 2019; Dahlin et al. 2015), or 6mm, on all studies that used other instruments (Lundström et al. 2018; Tateno et al. 2011; Mahbub et al. 2011).

Body Locations

Not all papers examined in this review gathered VPT data from the same body location. The locations on which data was gathered were: the pulp/fingertip of the index finger of the right hand (Dahlin et al. 2015; Ekman et al. 2019; Ekman et al. 2021; Lundström et al. 2018; Tateno et al. 2011); the pulp/fingertip of the little finger of the right hand (Dahlin et al. 2015; Ekman et al. 2021; Ekman et al. 2019; Mahbub et al. 2011); the pulp/fingertip of the middle finger of the right hand (Mahbub et al. 2011; Tateno et al. 2011); the dorsum of the middle phalanx of the ring and index fingers of the right hand (Mahbub et al. 2011); the first and fifth metatarsal heads in the sole of the right foot (Dahlin et al. 2015; Ekman et al. 2021); the heel of the right foot (Dahlin et al. 2015).

Frequencies That Were Studied

Of all the studies that were reviewed in this document, all but one gathered VPT data from more than one frequency. Ekman et al. (2019, 2021) gathered VPT data regarding frequencies of 8, 16, 32, 64, 125, 250, and 500 Hz; Lundström et al. (2018) regarding frequencies of 8, 16, 32, 63, 125, 250, and 500 Hz; Dahlin et al. (2015) regarding frequencies of 8, 16, 32.5, 64, 125, 250 and 500 Hz; Tateno et al. (2011) regarding frequencies of 3.15, 4, 5, 20, 25, 31.5, 100, 125 and 160 Hz; and Mahbub et al. (2011) regarding a frequency of 125 Hz.

Experimental Duration

Each of the reviewed studies had different experimental durations. Ekman et al. (2021)‘s had a duration of at least 4 minutes of experimental procedure per body location. Ekman et al. (2019)‘s report that each test of their study lasted approximately eight minutes. In Lundström et al. (2018), tests reportedly took an average of 20 min to perform, which included a period of installation, familiarization, and training, as established in their experimental protocol. In Dahlin et al. (2015), the authors reported that the test for each body location took about three minutes. Mahbub et al. (2011)'s had a relatively longer experimental time, due to the inclusion of a 30-minute period in which participants got accustomed to the temperature of the room, after which baseline VPT measurements were measured twice at an interval of 5 minutes between the two cycles. Following this, participants were asked to grip a handle for 5 minutes, during which vibrations were delivered to the hand through the handle, and, afterwards, three measurements cycles of VPT were conducted sequentially on each body location, with each cycle reportedly lasting between 5 to 6 minutes. Tateno et al. (2011) did not provide information regarding the duration of their experimental sessions.

Participants

The number of subjects that took part as participants, as well as their age, gender, and other characteristics, were varied between each of the reviewed studies. Ekman et al. (2021) collected data from 913 healthy subjects, between the ages of 18 and 90 years-old (mean 46 years; 620 women and 293 men). In Ekman et al. (2019), subjects were 20 healthy adults between the ages of 26 and 65 years (mean 46.0 ± 11.1 years; 10 male and 10 female). Lundström et al. (2018) had 148 male subjects, out of which 116 were manual workers exposed to hand-transmitted vibration and 32 were white-collar workers. Dahlin et al. (2015) had a total of 283 healthy participants, 146 girls and 137 boys between the ages of 8–20 years. In Mahbub et al. (2011), information was gathered from 8 male volunteers, with a mean age of 24 years old, and a mean body mass index of 21.9 kg/m2. In Tateno et al. (2011), 47 healthy Japanese office workers took part in the study, of which 30 were males (age: 23 to 40 years, mean 31.3 years) and 17 were females (age: 22 to 40 years, mean 29.8 years).

Results

From the results of their study, Ekman et al. (2021) concluded that VPT deteriorate progressively as a part of the normal human aging process, with age affecting thresholds for all frequencies. They also found that VPT curves followed a pattern in which the thresholds increased as frequency increased, but decreased between 32 and 125 Hz, at the finger pulps, but the same was not found at the metatarsal heads. The authors also found that temperature influenced VPT, with lower temperatures in the fingers resulting in decreased sensibility.

Ekman et al. (2019) found that participant's sensibilities to vibration seemed to improve over the course of re-measuring VPT over a period of months, as thresholds decreased for five out of the seven frequencies measured on the index finger, and for three out of seven frequencies on the little finger. However, the authors cautioned that these changes ranged between 2 and 10 dB, and did not always follow a downward trend.

Lundström et al. (2018) found no connection between thickness of the finger's skin, within the range of about 0.1–1 mm, and VPT for the test frequencies that were studied. The authors found that age had a negative impact on with VPT, with age decreasing participant's sensibility.

Dahlin et al. (2015) found differences in VPT measurements in different frequencies at both the fingers and foot, whit said differences also being related to age. They also found correlations between VPT in the finger pulps of the index and little fingers, especially at higher frequencies, in both genders. Correlations were also found between the three studied sites on the foot for both genders, with the exception, in boys, of thresholds at the metatarsal heads and the heel.

According to Mahbub et al. (2011), their results suggest that within and between-session measurements of VPT, collected with the HVLab Tactile Vibrometer on glabrous finger skin, were repeatable, but that the same could not be said for measurements on non glabrous finger skin. For this reason, the authors argue that it is better to measure VPT on glabrous skin. Additionally, regarding exposure to vibration, the authors found that VPT increased on non glabrous skin under 250 Hz, and that prior exposure to hand or arm vibration can impact VPT responses.

Tateno et al. (2011) found no large differences on VPT between genders, with the exception that VPT on female participants were slightly lower than those of male participants on some lower frequencies.

CONCLUSION

From the analysis of the instrumentation and experimental protocols employed on the reviewed papers, common aspects between the different works were noticeable. Regarding the choice of instrument, while the vibrometers used in each paper were not always the same, these devices followed the recommendations set by the international standards for the assessment of mechanical vibration (International Organization for Standardization 2003; International Organization for Standardization 2001), regarding both the required and optional components of a vibrometer. As many of the used instruments were of commercial original, this is to be expected. However, despite following the recommendations regarding vibrometer components, when it comes to the choice of algorithm, all papers used a method relying of continuous stimuli, which, according to the Standart, is less preferred than methods relying on intermittent stimulation, when assessing VPT. This decision might be due to either hardware restrictions on the part of the instruments that were used, or a preference for the time efficiency over the efficacy of the protocol, as Gandhi et al. (2011) suggested, although since justification for the use of the von Békésy algorithm is not offered in any of the papers, this cannot be confirmed. However, considering the high number of participants and the high number of studied frequencies in some of the reviewed papers, it is possible that time efficiency was indeed the reason for using the von Békésy algorithm in said papers. As for the choice of studied frequencies, there was a big overlap between each of the studies, which allow for easier comparisons to be made between the results obtained in each study, although these selections of frequency still resulted in a big range of other frequencies left unstudied. It is possible that hardware limitations also weighed on the decision of authors to study some frequencies over others.

For the above-mentioned reasons, we believe that the characteristics of the instrumentation had an impact on the experimental protocols used in at least some of the studies that were reviewed. This provided a motivation to develop our own instrumental solution, that is more versatile in its use for assessing the perception of vibration in the hands of human subjects, with the goal of providing researchers with more freedom and customization options when selecting or developing experimental protocols. For example, this new instrumental approach allows the measuring of tactile vibration on different fingers at the same time using piezoelectric actuators. The results from this work, an instrument which we named Hand Vibration Threshold Mapper (HaViThreMa) testing platform, will be the focus of another paper.

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